# VIRTUAL REALITY
# AN AIR COMBAT T&E PERSPECTIVE

R. R. Smullen, Jr.
Deputy Director for Engineering
Naval Air Warfare Center
Patuxent River, Maryland 20670

R. E. Nowak
OCC Program Manager
Naval Air Warfare Center
Patuxent River, Maryland 20670

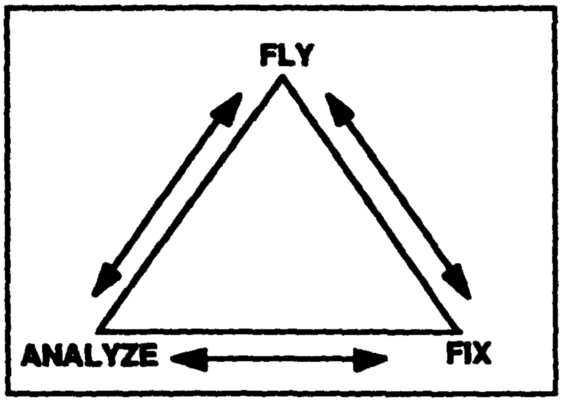


## Abstract

The exponential increase in the complexity of modern aircraft and aircraft systems has made it extremely difficult to assess the mission effectiveness of Naval aviation weapons systems against new threats. Flight testing has historically been the primary source of data on the effectiveness of our aircraft and weapons, but flight testing is expensive and limited in the questions it can answer. For this reason, the U.S. Naval Air Warfare Center has embarked on the development of a fully integrated, multi-spectral ground test facility called the Air Combat Environment Test and Evaluation Facility (ACETEF) which is capable of creating a "virtual" test environment for testing advanced weapon systems. Four primary factors have driven the development of the ACETEF. First is test realism. Flight testing lacks operational realism in that it cannot create the test conditions for determining the operational utility of our weapons systems in the dense threat environment of real combat. Second is security. Flight testing is inherently a public event. Third is cost. Flight testing is expensive and compounded by the added risk of mishaps. And last, the limited combat situations of the past few years have documented the need to evaluate the interoperability of our systems. Navy, Marine, Army, Air Force, and allied forces must be able to communicate and interact. Through the use of a unique combination of simulation and stimulation techniques the ACETEF permits man-in-the-loop ground testing of fully integrated aircraft and aircraft systems in a virtual environment that closely parallels actual combat, while remaining secure, safe and cost effective.

## Background

The genesis of the Air Combat Environment Test and Evaluation Facility (ACETEF) began in the mid 1970's. At that time there were three new aircraft programs converging on what was then the Naval Air Test Center, and is now known as the Aircraft Division of the Naval Air Warfare Center. The F/A-18, AV-8B and the LAMPS MK-III Helicopter programs were all at least an order of magnitude more complex than any aircraft we had ever seen at Patuxent River. The aircraft had a number of features in common. First, they each incorporated a federated computer architecture. That is a number of linked computer systems, each executing its own specific mission within the airplane. The most complex of the previous generation airplanes had used a centralized architecture, with only one or perhaps a few processors. The second feature that these aircraft had in common was their




Fly-Fix-Fly Methodology
Figure 1

data bus architectures. The linking technique for these federated processors was a new "high speed" data bus based upon the Military Standard 1553 protocol. The third and final common feature was their extensive use of software. All three aircraft used literally millions of lines of code, and in the 1970's that was awesome.

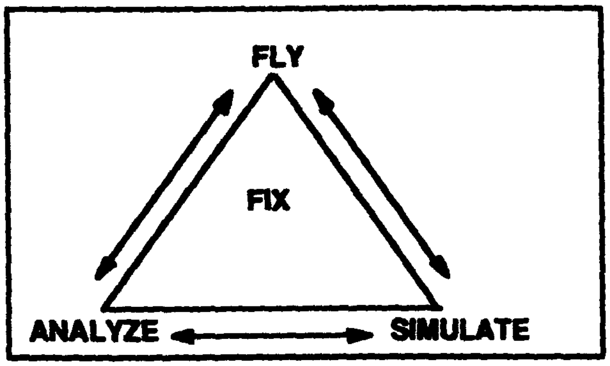
The arrival of these programs caused the flight test engineers at Patuxent to take stock in there processes, procedures and methods of testing. It was clear that the increased complexity of these airplanes and the lack of any additional time in the test process presented a problem. Some early calculations in the F/A-18 program were typical of the magnitude of the problem. A three dimensional matrix was formed where one axis represented the weapon delivery modes and sensor combinations available on the airplane. The second axis represented the weapon release profiles that the systems were capable of. And the third axis represented the weapons which could be carried on the airplane. In each "cell" formed by this 3D matrix, was placed the number of weapons that needed to be dropped, fired, or shot from the airplane to collect statistically significant results. For a typical weapon/sensor/profile combination this was somewhere between 18 and 36 weapons. The resulting matrix characterized over 250,000 weapons that need to be released during the test process. Even the most optimistic calculations resulted in over 20 years of testing to collect this amount of data. And this was just the air-to-ground capability of this multi-mission airplane.

The methodology that was used in the 70's is shown in Figure 1. While we were often accused of a Fly-Fix-Fly methodology, this was not the case. There was without doubt an analysis phase of the method. After the flight, the data was downloaded, analyzed and fixes for the system developed. New hardware/software were installed and the process was continued.

In an effort to make the process more efficient, the flight test engineers looked around at what private industry and the other military services were doing to see if there were ways to become more productive. What they found were some of the first applications of simulation technology to testing of avionics systems. The engineers brought some of the best of these ideas back to Patuxent and started the implementation of the methodology shown in Figure 2. The addition of the *simulation* step to the process helped make the flight testing more productive. By practicing the flights on the ground before going in the air, fewer flights were required to achieve difficult and potentially dangerous data points. But even this new methodology was not enough. You couldn't use simulation technology for testing on the ground, because the simulation was only as good as what you thought the systems would be. Another step was needed.

The final addition of *stimulation*

technology to the methodology is shown in Figure 3. This is the method that is still used in the ACETEF today. Aircraft and their systems are stimulated on the ground by means of digital or analog signals to make them believe they are in flight in a realistic warfare environment. That environment may include other friendly elements, threat or enemy elements, and neutral or third party elements. The synergistic combination of flight testing, and ground testing as

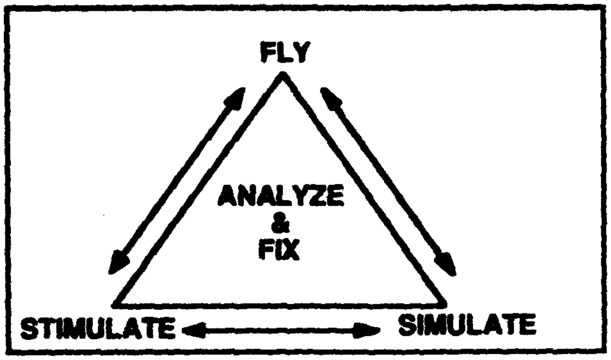



Revised Aircraft T&E Methodology
Figure 2

shown in this diagram is the basis of the ACETEF which will be described in the remainder of this paper and is the basis for the testing philosophy currently embraced by the U.S. Department of Defense.

## ACETEF

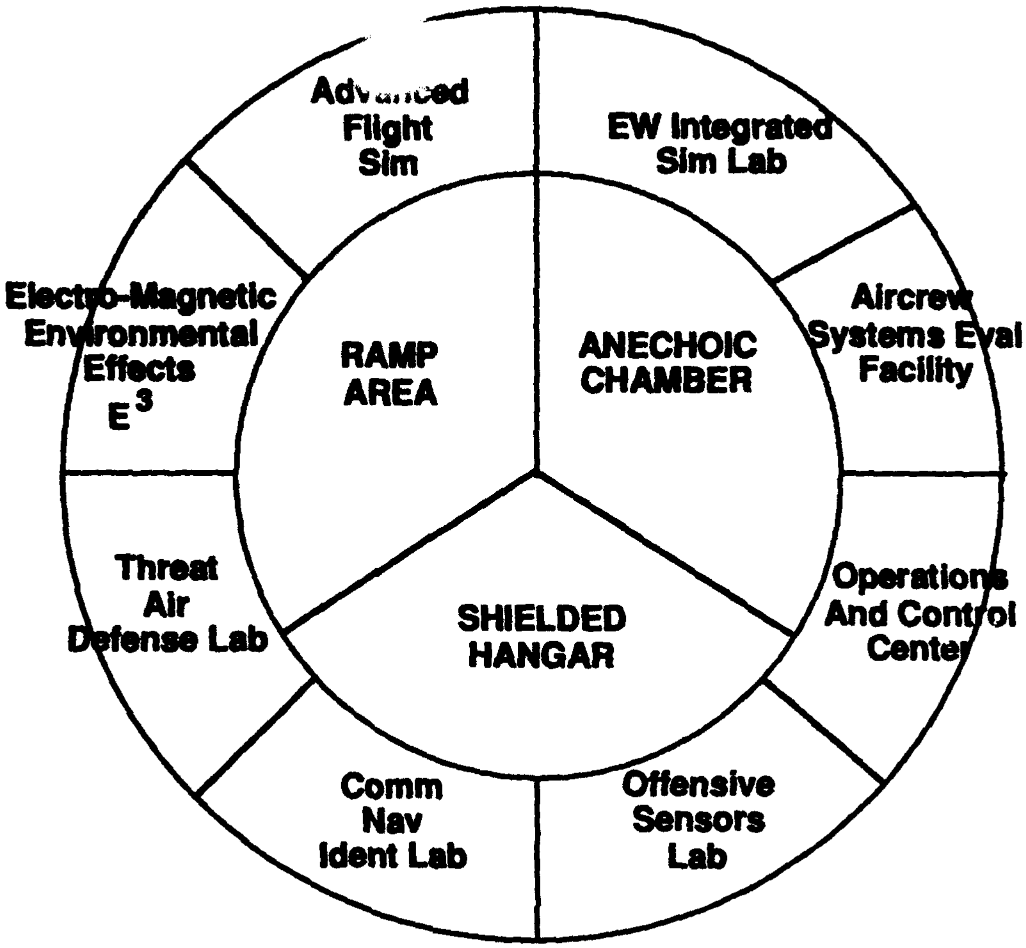
The diagram shown in Figure 4 shows the primary elements included in the ACETEF. The inner portion of the circle represent the locations where we place the test article during the test. The outer portions of the wheel represent the laboratories that are used to provide simulation and stimulation of the test article. The best test environment for a test article is our anechoic chamber. One hundred feet long, sixty feet wide and forty feet high, the chamber is able to house all of the U.S. Navy's tactical sized aircraft and most of the other Services tactical aircraft. The door to the chamber is forty feet wide and twenty feet tall, the same dimensions as the elevator on a




New Aircraft T&E Methodology
Figure 3

U.S aircraft carrier. The interior of the chamber is covered with anechoic material to absorb Radio Frequency emissions from the airplane and to prevent unrealistic "reflections". The walls themselves are covered with welded steel plate to provide a high level of isolation between the inside of the chamber and the outside world. This isolation provides a "quiet" electromagnetic environment for testing and also supports secure testing requirements. Typical isolations in excess of 100 dB are achieved in the chamber. In the ceiling of the chamber is a thirty ton crane. The crane is used to suspend the aircraft/system under test above the floor and enables placement of anechoic materials below the aircraft, as well as, on the sides and above the aircraft.

Unfortunately, the anechoic chamber is a very busy facility and is not always available for every test program. For that reason we have a shielded hangar to support tests that either can't get into the chamber because of scheduleor because the test asset is too large to fit in the chamber. The shielded hangar walls are covered with a metal screen to provide a limited degree of isolation. Typical isolation




ACETEF Laboratory Components
Figure 4

values of 20 - 30 dB provide a better environment than is available outside. Placement of portable anechoic material covered walls around the test articles help some with the problems of reflections. The shielded hangar is 300 feet long and 150 feet wide, allowing six to eight simultaneous test programs to operate at one time.

There are some aircraft that will not fit even in the shielded hangar. The C-17, for example, had to be tested on the ramp outside our hangar because its "T - tail" would not fit through our doorway. Ramp space is used at ACETEF to do high power testing such as Electromagnetic Pulse (EMP) where stimulators simulated the pulse generated during an atmospheric nuclear detonation.

The outer spokes of the wheel show the laboratories of the ACETEF. These labs can be separated into three basic categories. First there are the labs that stimulate the onboard offensive systems of the test article. Second there are laboratories that stimulate the defensive system. And finally, there are those labs that provide for phenonlogical or environmental effects, such as electromagnetic environmental effects. We will discuss the laboratories in more detail later in this paper.

## Life Cycle Test Process

At this point I would like to digress a

moment and talk about the U.S. DoD life cycle test process. In order to truly understand the ACETEF approach, it is important to see where it fits into the total process. Figure 5 shows a "waterfall" chart that depicts the current life cycle process embraced by DoD in the U.S. It starts up at the top with Modeling and Simulation (M&S). At this point in the process, the test article is still theoretical and is represented by a set of requirements. Coded into a batch mode simulation environment, the 1's and 0's implementation of the new system are evaluated for effectiveness for the first time. Once studies show that the new program has merit, the first hardware elements are developed. These developments occur in what are call Hardware-In-the-Loop (HIL) facilities. HIL's run these early brass board or prototype hardware on spread benches where development engineers can access the systems to determine performance characteristics. As more and more elements or subsystems become available, benches are connected to benches in what become the first vestiges of Integration facilities. These integration facilities will remain with successful systems forever, providing life cycle support services. Once the system, or at least major portions of it, have been integrated, it is time to install it in the host platform. At this point in the process we are able to transition to Installed Systems Test Facilities (ISTF). Here the systems and subsystems get their first workout in the environment they will live in, for example inside of an aircraft. The last step in the process is the flight testing which is performed on an Open Air Range (OAR). OAR testing is the pinnacle of the test process, but is the most expensive part of the process. As you move from left to right on this chart, the cost of testing and the fidelity of the testing go up. For that reason, it is most cost effective to find problems as early in this process as possible. The last box on this chart is the Measurement Facilities box. Measurement facilities can be used at any step in the process and are used to characterize or measure elements of the test article. Radar cross section facilities, antennae pattern ranges and engine thrust stands are all examples of measurement facilities.

The arrows on the top of the waterfall diagram show the typical flow of the testing, but it is also important to note the feedback arrows on the bottom. When the process is executed at its best, each step remains in operation throughout the test process and is updated based upon information collected about system performance from the latter steps in the process. For instance the M&S used at the beginning should be continuously updated to represent the actual system performance measured as we move though the HITL, Integration Facility, ISTF, and OAR testing phases. This would allow continuous analysis to ensure that the original precepts which served as the basis to begin the system development are still valid.

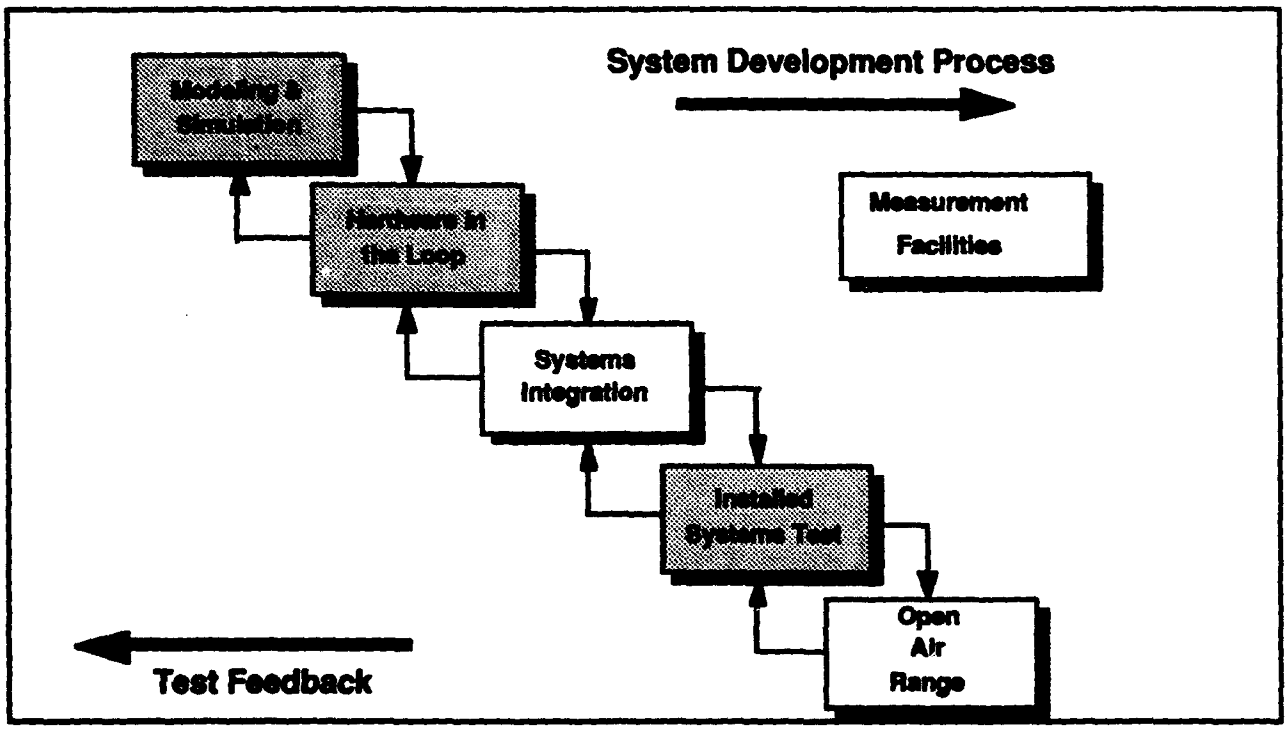
A last note on this diagram. I have noted that ACETEF is, by definition, an Installed System Test Facility or ISTF. However, the development and operation of an ISTF provides inherent capabilities in some of the other areas of the test process. For example, ACETEF also incorporates significant M&S capability in order to stimulate test article systems and simulate the test environment. ACETEF also provides HITL capability and some Measurement facility capability.

The user community for the ACETEF is shown in Figure 6. ACETEF users represent virtually every facet of the DoD's acquisition test process and range from those involved in studies and analysis at the beginning of a program, to the operational testers that put the final stamp of approval on a new weapon system. The ACETEF has provided Operations test support for all three branches of the U.S. military.

## ACETEF Capabilities

I would like to return now to the ACETEF and describe some of the key capabilities that characterize a full capability ISTF. Man-In-the-Loop (MIL) capability is critical for mission level ISTF testing. Parametric studies and engineering analysis may be performed with computers "driving" the test platform, but when testing at the mission level, actual aircrew are required to conduct accurate testing. Even with today's highly integrated and computer enhanced weapon systems, it is the aircrew that are making mission critical decisions and act as the final integrator of data displayed in the cockpit. Additional real players may be required in a test to allow the same level of fidelity for associate players (wing man, command/control/communications (C3) operators, threat systems operators, etc.). Multiple simulations with real operators is referred to as Men-In-the-Loop capability. Realistic scenarios for mission level testing may require hundreds, if not thousands, of players to be realistic. These Many-on-Many scenarios often consist of a combination of Red, Blue and White (Threat, Friendly and Neutral) players whose systems are operating in the real world Multi-Spectral environment. A full capability ISTF, like the ACETEF, allows the mixing of Real players (actual hardware), Synthetic players (digital models) and Hybrid players (a combination of both).

ACETEF also provides two levels of threat simulations. High density threat environments are simulated at RF with its Open Loop signal simulators. These simulators are driven by the scenario simulation, but do not include actual threat or simulated threat system hardware. A second class or simulators includes actual or hardware




U.S. Department of Defense T&E Life Cycle
Figure 5

simulations of systems. These Closed Loop signal simulators allow engineers to test the effectiveness of countermeasures techniques. Finally, in the real world both friendly and threat systems operate under the umbrella of a Command, Control and Communications network. ACETEF provides simulations of all C3 elements.

**Study Directors**
**Concept Explorers**
**System Developers**
**System Integrators**
**System Developmental Testers**
**System Operational Testers**

ACETEF User Community
Figure 6

Simulated Warfare Environment Generator (SWEG)

There are a number of simulation and stimulation facilities throughout the United States, and indeed the world, that have capabilities similar to the laboratories that make up the ACETEF. The single element of the ACETEF that makes it unique is the degree of integration between the laboratories that has been achieved. The central core that makes that integration possible is a software program called SWEG.

SWEG is based upon the batch mode war gaming and analysis software program Suppressor. Suppressor was developed by the Air Force several years ago to run cost and operational effectiveness studies and is still in use by all three Services today in that capacity. SWEG made two major modifications to Suppressor to become the kernel or scenario controller for the ACETEF. First the program was modified to run in Real-Time. This was achieved by encasing Suppressor in a shell that constrained it to run in real-time and some clean-up of the code to limit processing requirements. Processing requirements have never really been an issue with SWEG given the recent and continuing advances made in computer hardware. Most desktop computers today are capable of running SWEG with hundreds of player scenarios in real-time. The second major modification to Suppressor was the key to the ACETEF approach. Suppressor was modified to allow *external control* of one or more of the players in its scenario. Instead of Suppressor/SWEG determining the movements and actions of a given player, those inputs were provided to SWEG by a flight simulator, threat simulator, or some other man-in-the-loop element of the ACETEF.

SWEG sits at the center of the ACETEF architecture and is linked to every laboratory component. The primary link is SCRAMNET, a shared memory high speed fiber optic network which uses reflected memory in processors in each of the laboratories to allow real-time communications of the various simulations. Linked lists from SWEG are provided in these common memory areas to provide ACETEF simulations with state vectors and status information on every player within the current simulation. Additional instrumentation, communications, and control fiber optic networks are also included in the ACETEF architecture.

Programmatic Support

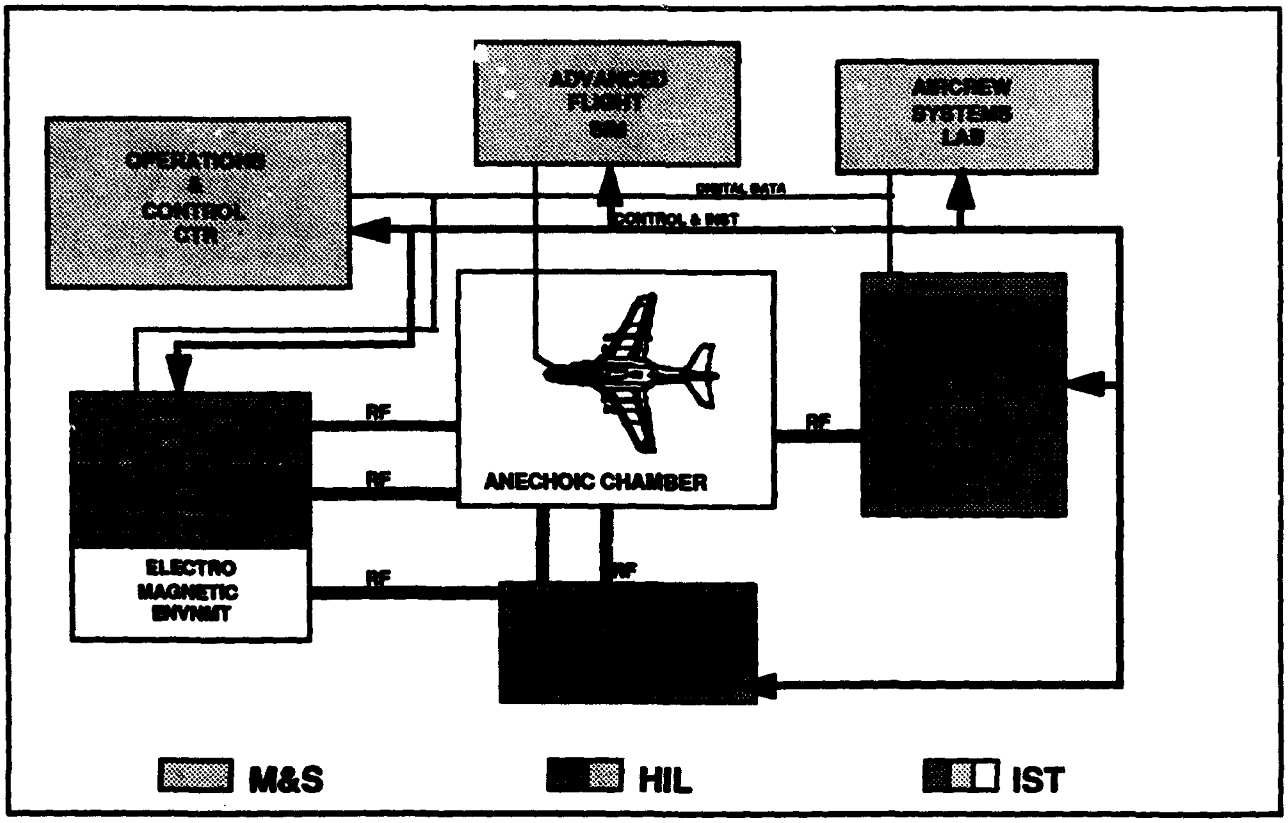
As described earlier, the ACETEF provides support in a number of the test and evaluation life cycle processes. Figure 7 shows how the laboratories in the ACETEF map to the different phases of this test process.

During the initial studies and analysis phase of a program, three of ACETEF's laboratories are available to provide support. The Operations & Control Center (OCC) is the home of the SWEG software and is often called upon to run the software in either real-time or non real-time for study scenarios. The Advanced Flight Simulator (AFS) provides the man-in-the-loop function for the ACETEF and provides simulated cockpits, aerodynamics simulations, and avionics simulations.

AFS houses a 40 ft dome simulator and a 6 degree-of-freedom motion base simulator in addition to several lower fidelity fixed base simulation stalls. The visual systems of the AFS are linked to the SWEG so that other players in the scenario, whether real, synthetic, or hybrid, show up in the dome or motion base visuals. The final element for this digital implementation of the new test article is the Aircrew Systems Evaluation Facility (ASEF).

ASEF houses a number of low to medium fidelity cockpits with reprogrammable displays and controls. ASEF specializes in optimization of the Man - Machine interface and includes a number of special purpose tools to allow aircrew to try out different cockpit layouts. ASEF is also linked to SWEG and may be operated as an associate player in ACETEF scenarios. Speed and flexibility are the keys in human factors support in ASEF.

Once the first elements of the test articles hardware become available, the ACETEF can begin to operate in its HIL mode. Several additional laboratories are brought on-line in this phase, in addition to the AFS, OCC and ASEF, which continue to operate in the scenario. The Electronic Warfare Integrated Systems Test Laboratory (EWISTL) provides the open loop RF signal generation for the ACETEF. While primarily used to generate threat radar signals, EWISTL can




ACETEF Laboratory to Support Function Mapping
Figure 7

generate over 1,000 threat radar signals for friendly, threat or neutral players in a SWEG scenario. SWEG provides control signals to the RF generating hardware in EWISTL to control mode and direction of arrival of each RF signal. The Threat Air Defense Laboratory (TADL) provides man-in-the-loop and hardware-in-the-loop closed loop signal generation. The Communications, Navigation, and Identification Laboratory (CNIL) is one of the newer laboratory components in the ACETEF. CNIL provides stimuli for CNI equipment and can even provide a Global Positioning System constellation of satellites if required. CNIL, like the EWISTL, is capable of providing Red, Blue and Gray signals to the test article. The last laboratory in this phase is the Offensive Sensor Laboratory (OSL). OSL, like CNIL, is a new laboratory in the ACETEF family. OSL currently provides stimulation capability for air-to-air radar modes of the test article and is developing capabilities to stimulate radar air-to-ground modes and infrared sensor stimulation techniques.

The last phase of testing I want to address is the installed systems test phase. In this phase the test article is usually an entire airplane, although missiles and satellites have also been tested in this facility. The anechoic chamber is the most obvious addition to the test suite in this phase. As described earlier, the airplane or other test article is usually suspended from the ceiling with a 30 ton crane which allows anechoic material to be placed all around the test article. The Electromagnetic Effects Environment Generating System (EMEGS) is also brought on-line in this phase. EMEGS has frequency coverage similar to the EWISTL, but provides high power output for a few (32) emitters, versus low power for many (1024) emitters in EWISTL. EMEGS allows ACETEF to simulate the demanding high field strength environment that is unique to the aircraft carrier environment.

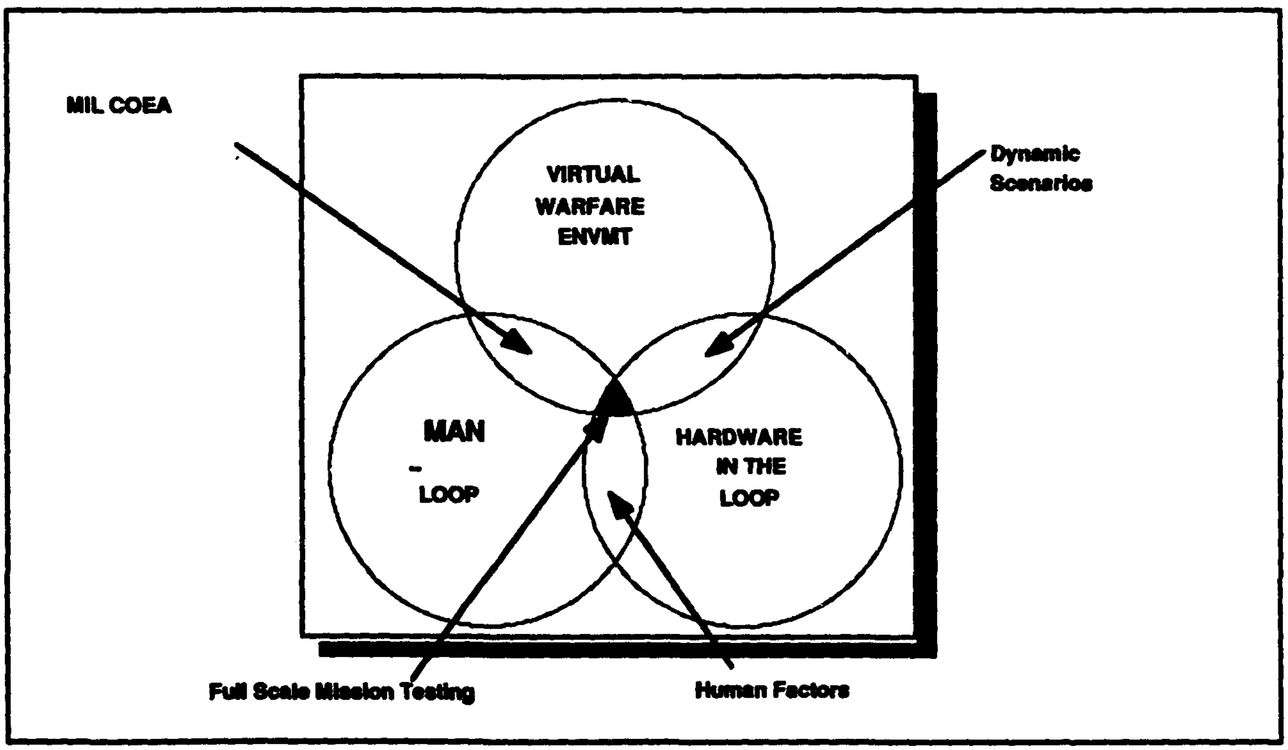
## ACETEF Concept

The facility that I have described here uniquely brings together several capabilities at Patuxent River, as shown in Figure 8. First it provides a Man-In-the-Loop environment to allow aircrew to take part in simulation testing. This MIL function will remain important as long as the aircrew are involved in data fusion and mission critical decision making in our weapon systems. The second element brought to bear on the testing problem is ACETEF's Hardware-In-the-Loop capability. Real hardware being stimulated to determine its performance at both mission and functional levels. This can be hardware operating on a spread bench, or installed in the host platform. The hardware can represent an individual subsystem or the entire system integrated and executing a realistic mission scenario. The last element that ACETEF creates is its Virtual Test Environment. This is important for both parametric and mission level testing and allows ACETEF to create test environments that can represent any place in the world with any combination of threats, friendlies and neutral players imaginable. ACETEF can provide electronic orders of battle, threat densities, and multi-player environments that would be unaffordable, if achievable in an open air range environment, while maintaining the repeatability that is characteristic of ground testing.

While these are significant capabilities, it is the ability to simultaneously bring all three on-line for a single test that makes ACETEF unique, as shown in Figure 8. Simultaneous application of Man-In-the-Loop and Hardware-In-the-Loop allows human factors engineers to characterize system performance in a dynamic environment. Man-In-the-Loop coupled with the Virtual Environment provided by SWEG allows studies and analysis teams to insert real aircrew in the earliest stages of testing. Hardware-In-the-Loop coupled with SWEGs Virtual Environment allows hardware testing with dynamic and interactive versus static canned scenarios. And finally, at the very center of the diagram, all three elements of the ACETEF come together to allow full mission testing of the test article with its crew.

## Summary

This paper has attempted to describe the new generation of ground test facilities that have arisen in response to the ever increasing complexity of our aircraft and aircraft weapon systems. Bringing to bear the latest in simulation, stimulation and software technologies, these facilities are rewriting the textbooks on testing electronic systems. These systems can now be tested in environments that represent virtually any current or projected combat scenarios, a capability which does not exist at any flight test range, and thus creating new dimensions in test and evaluation technology.




The ACETEF Concept
Figure 8